Processing Software at JABLTCX and Processing Acceleration Opportunities

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Executive Summary

The current airborne LIDAR survey system CHARTS is SHOALS 3000T20-E that collects voluminous data from its variety of on-board sensors. It gathers LIDAR bathymetric and topographic data, CASI hyperspectral data and RGB digital image data. The purpose of this airborne system is complete littoral zone surveying and mapping for USACE and US Navy. The huge volume of currently collected digital data and a foreseen increase in the data gathering capabilities of the next generation survey system creates a need to develop faster methods to process collected data. This report looks at the existing processing paths, processing hardware and software to identify opportunities to accelerate processing and delivery of final hydrographic, topographic and hyperspectral products by using high performance programming techniques such as parallelization, vectorization and in memory processing. A small number of targeted improvements have been identified to be discussed with software vendors.

The software deployed at JABLTCX can be divided into a few main categories:

- vendor and sensor-specific software designed to access raw sensor data
- cleaning, editing and validating software for datasets of LIDAR points
- custom software to extract data for a specific geographic area
- commercial GIS-type software to process datasets of points into grids, various elevation models, raster images or vector maps
- commercial software to generate image mosaics from hyperspectral and RGB data
- emerging software for optical-data fusion between LIDAR and CASI sensors

The primary operating system is Microsoft Windows XP, both 32-bit (on most desktops) and 64-bit versions. The Linux (Fedora Core 4) operating system is used on all file servers, both 32-bit (most) and 64-bit. The commercial application software is all thirty-two-bit. The custom software and the US Navy PFM_ABE software suite are running on the 32-bit files servers.

The following are the newer processing capabilities offered by the mass computer market:

- larger computer memory (RAM) for desktops, workstations and servers, on the order of tens of gigabytes
- affordable dual and quad processor systems, with dual core processors
- larger hard drives with sizes at least 200 GB and inexpensive RAID arrays
- mainstream CPUs from Intel and AMD with expanded vector instruction sets as SSE3
- sixty-four-bit operating system environments from the mainstream vendors

There exist mature programming techniques to benefit from such advanced features. The programming techniques include code parallelization, code vectorization and programming for in-memory (in-core) processing.

Here is a list of main processing stages at JALBTCX that will benefit from code parallelization, large RAM and code vectorization. In the processing of LIDAR data, the following places for improvement have been identified:

- the Automatic Processing (waveform processing) step in GCS/DAVIS. The primary improvement technique is code parallelization.
- the cleaning, editing and validation step in editing software GCS/DAVIS/Fledermaus and PFM_ABE/ABE. The primary improvement techniques are using large RAM and improving network bandwidth to storage servers.

In the processing of hyperspectral data, the following place for improvement has been identified:

- the geocorrection (image geo-rectification) step of CASI images in ITRES Standard Processing Software. The primary improvement techniques are code parallelization and using large RAM.

In the processing of RGB images, the following places for improvement have been identified:

- re-sampling (image rectification) step in ERDAS. The primary improvement techniques are code parallelization, using large RAM and code vectorization.
- mosaic generation step in ERDAS. The primary improvement technique is using large RAM.

In the emerging sensor fusion software (LIDAR and hyperspectral data), the following place for improvement has been identified:

- inversion step in the Rapid Environment Assessment software. The primary improvement technique is code parallelization.

Currently, no software at JABLTCX is capable of using multiple processors (CPUs) for the core part of data processing. Only one software, QT Modeler is capable of utilizing large RAM, up to 2GB. None of deployed software is yet capable of utilizing the new memory limit of 4GB of the sixty-four-bit version of Microsoft Windows for the 32-bit applications.

The expected effect of improvements is to shorten the overall processing time and to be able to handle larger datasets. Improvement of software is to be achieved by cooperating with vendors to re-code application software for COTS computers with small number of processors (2, 4 or 8) and a large RAM (at least 16 GB). Software vendors should be encouraged to utilize the full 4 GB of RAM in their 32-bit software and preferably to code the 64-bit applications. In the case of the editing software as Fledermaus and ABE, the additional avenue of improvements include changing methods of accessing large datasets via optimized network or perhaps by utilizing a client side network file cache system.

Report Conclusions and Recommendations

For convenience of a reader all conclusions and recommendations of the report are presented here.

- **Microsoft Windows 64-bit And 32-bit Applications**

  Conclusion: The 32-bit and 64-bit versions of Windows applications can be run side-by-side under the 64-bit Microsoft Windows XP Professional operating system. The current introduction of the 64-bit Microsoft Windows operating system should have a positive effect on the performance of Windows applications as ArcGIS, QT Modeler, Lidar Analyst and similar GIS programs used at JABLTCX, even if 32-bit versions were still used. Future 64-bit versions of GIS software are predicted to perform much better, thanks primarily to larger memory limits.

- **Linux 64-bit and 32-bit Applications**

  Conclusion: The 32-bit and 64-bit versions of Linux applications can be run side-by-side on the 64-bit Linux servers. Future 64-bit versions of software are predicted to perform much better, thanks primarily to larger memory limits.

- **Creating Software Capable of Using Large Memory**

  Observation: Only one software at JABLTCX, called QT Modeler, is capable of using large memory, up to 2 GB of RAM.

  Recommendation: Vendors of software used at JALBTCX should be encouraged to take the advantage of available large RAM and to re-design their software accordingly. Specifically, JABLTCX should initiate dialog with developers of:

  - Fledermaus and ABE , to improve handling of PFM datasets and GUI responsiveness. A large memory in a processing computer makes possible to eliminate the intensive I/O to and from a PFM on a hard drive by explicitly utilizing memory in the code or even by creating a primary working copy of the PFM in RAM.
  - ITRES Standard Processing Software, to improve georectification and mosaic (PIX) files handling. A large memory in a processing computer makes possible to allocate large arrays in RAM to build larger chunks of the rectified images and mosaic in the memory before committing them to the hard drive.
  - ERDAS, to improve RGB images rectification (resampling) and mosaic (IMG) files handling. A large memory in a processing computer makes possible to allocate large arrays in RAM to build larger chunks of the rectified images and mosaic in the memory before committing them to the hard drive.

- **Creating Software Capable to Utilize a Small Multiprocessor Computer**

  Observation: None of the current software used at JABLTCX, both commercial and custom, is capable to utilize multiple processors (CPUs) for the core data processing, even that the operating systems (Microsoft Windows, Linux) and most Graphical User Interfaces (GUIs) of deployed software are fully threaded and able to use multiple processors (CPUs).

  Recommendation: Consult software vendors to discuss feasibility of using software parallelization to accelerate processing of:

  - LIDAR waveform processing (the Automatic Processing function from GCS/DAVIS). The GCS software reports that this step takes time comparable to the collection time.
  - geocorrection step from ITRES Standard Processing of the hyperspectral CASI data. Tests found that the ratio of the collection time to the geocorrection run time is 1 to 3.5. The applicable parallelization techniques could include data partitioning in the time dimension, or partitioning along the spectral bands.
  - RGB images rectification (resampling) and mosaic generation, using ERDAS software. The user reported average speed of rectification (resampling) of 400 images in one hour. The applicable parallelization techniques could include task (rectification) spreading among processors.
  - inversion step in the Rapid Environment Assessment software. Multiple independent inversions, possible in hundreds, are preformed on a single spectral image. The applicable parallelization techniques could include task (inversion) spreading among processors.

- **Using Vector Instructions – Streaming SIMD Extensions**

  Recommendation: Consult software vendors to find out their current level of using the vector instructions in their products for image processing and possibly discuss feasibility of using the SSE3 vector instruction set to accelerate processing of:

  - hyperspectral CASI data, with ITRES software or ENVI
  - RGB image mosaic with ERDAS

- **Using Large Local Disks to Mitigate I/O Bottlenecks Over Network**

  Recommendation: Executing an application with I/O drive activities done locally w/t the CPU seems to be the most optimal way of designing processing to eliminate bottlenecks of I/O over network. Review network connections from all processing desktops to servers and use available connections at full duplex Giga Ethernet. Consult software vendor of GCS and Fledermaus 3D to find the ways to mitigate I/O hard drives activities over a network for working with PFM datasets and LIDAR source data files.

- **Improving Data Processing Progress Tracking**

  Recommendation: Improve management of survey data post processing activities and individual processing task assignment. Consult software vendors to find software for task reporting and visualizing. A simple, open source solution is recommended to avoid costs of up keeping.

- **Improving Metadata Generation**

  Recommendation: Optech and ITRES should be consulted on designing metadata templates for the current sensors. A cross-platform (Microsoft Windows and Linux) metadata tool should be employed to aid metadata management. A future airborne survey system should include requirements to automatically generate metadata for raw data from sensors.

- **Future – COTS Processing Computer Hardware After Four Years**

  Target Computing Platforms: The COTS desktops will be at least dual processor computers with at least 16 GB of RAM, and 600 GB hard drives. The COTS computational workstations will have at least four CPUs, 32GB of RAM and a RAID storage of 1.6 TB. A COTS Linux server will have at least 8 CPUs, 64 GB of RAM and 8TB of storage. Computers will be running the 64-bit operating systems as Microsoft Windows and Linux.

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1 Introduction

The report is a review of the processing software and hardware currently used at the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTCX) located in Kiln, MS. JABLTCX operates an airborne LIDAR survey system SHOALS 3000T20-E called CHARTS. This airborne system collects voluminous data from its variety of on-board sensors – bathymetric LIDAR, topographic LIDAR, hyperspectral imager and color camera. The huge volume of currently collected digital data and a foreseen increase in the data gathering capabilities of the next generation survey system creates a need to find faster methods to process collected data. This report looks at the current processing paths, processing hardware and software to identify opportunities to accelerate processing and delivery of final hydrographic and topographic products.

In this review, the goal is to identify processing steps that could benefit new processing resources available in the computer Commercial Off The Shelf market place. The following are the newer capabilities offered by the mass computer market:

- larger computer memory for desktop computers, workstations and low-end servers, on the order of tens of gigabytes
- affordable dual and quad processor systems, with dual core processors
- larger hard drives with sizes at least 200 GB and inexpensive RAID arrays
- mainstream CPUs from Intel and AMD with expanded vector instruction sets
- sixty-four-bit operating system environments from the mainstream vendors

All of the above hardware and software features are not new in commercial and scientific areas. In the past, these were reserved for high performance computing, mainframe computing, commercial servers and enterprise business application processing infrastructure. There exist already mature programming techniques to benefit from such advanced features. The programming techniques include code parallelization, code vectorization and code designing for in-memory (in-core) processing. The mainstream code parallelization methods include threading, Message Passing Interface and OpenMP. For small, tightly coupled processor systems (usually with dual or quad motherboards) threading is an efficient technique that is now completely supported by both Microsoft Windows and Linux operating system environments. The code vectorization methods depend on processor specific instructions that operate on long vectors of data. Currently, because of the strong competition between Intel and AMD, both these manufacturers support in their popular processors the same set of vector instructions, called Streaming Single Instruction Multiple Data Extensions 3 (SSE3). Ten years ago the main computer memory was very expensive, and the size of the data was usually much larger than available memory. Most computer programs were designed to operate with a very small memory footprint and relied on utilizing a much larger but slower hard drives. Currently, a desktop with a few Giga bytes of RAM became affordable. The ability to use larger memory is strengthened by increasing maturity of the popular 64-bit operating system environments as Microsoft Windows XP and Linux.

For convenience of the reader Section on page iii gathers all recommendations of this report. Section 3 briefly describes sensors available in SHOALS 3000T20-E. Section 6 covers processing in the air. Section 6 presents various categories of application software used to process raw sensor data and to generated final products. Section 7 contains a short overview of computing hardware and networking at the JABLTCX main office. Section 8 describes processing that is undertaken in a survey field office. The positive effects of the 64-bit operating systems on potential performance of the 32-bit applications are described in Sections 9 and 10. Next sections (11-14) identify processing steps that could potentially benefit from availability of larger RAM, multiple processors, vector instructions and larger hard drives. Recommendations are presented to use specific programming techniques for improvements of application software to accelerate overall processing. Section 15 presents a recommendation for introducing at JABLTCX a lightweight software for the processing progress tracking. In Section 16 a recommendation to streamline the generation of metadata is formulated. Section 17 describes our assessment of future computing hardware.

2 Background Information

The current Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system is Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) 3000T20-E unit that was built by Optech Inc. This airborne survey system is operated by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTCX) located in Kiln, MS. JABLTCX is a partnership between the U.S. Army Corps of Engineers (USACE), the U.S. Navy, specifically, the Naval Meteorology and Oceanography Command and the Naval Oceanographic Office (NAVOCEANO), and the National Oceanic and Atmospheric Administration. The center is staffed by personnel from USACE and NAVOCEANO, and contractors from Fugro Pelagos, Inc. The survey system is primarily flown on small commercial aircraft contracted from Kenn Borek Air, Ltd.

3 Current Sensor Configuration

The SHOALS 3000T20-E system consists of multiple sensor subsystems:

- the hydrographic LIDAR subsystem
- the topographic LIDAR subsystem
- the hyperspectral radiometer subsystem ([4])
- the high-resolution digital color (RGB) camera ([8])
- the positional sensor

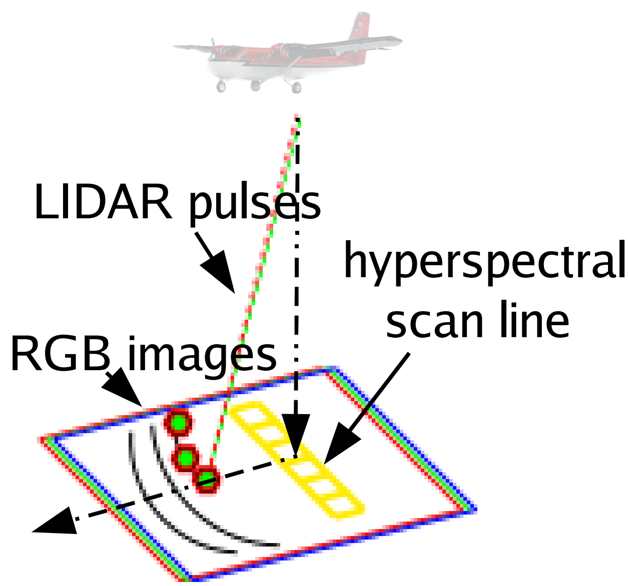


Figure 1: Airborne Data Collection

The hydrographic LIDAR subsystem is 3000 Hz scanning bathymetric sensor utilizing green (532nm) and infrared (1064nm) laser pulses. The topographic LIDAR subsystem uses a separate infrared laser, pulsing at 20kHz. Both topographic and bathymetric LIDAR sensors share most of the optical path, and only one LIDAR sensor is operated during a single survey pass. The hyperspectral radiometer subsystem is the Compact Airborne Spectrographic Imager (CASI) 1500 made by ITRES Research, Ltd. The down-looking digital color camera is DuncanTech DT4000. Still images are captured with rate 1 Hz.

Positional data is provided by SHOALS's Position and Orientation System (POS) consisting of INS and GPS, integrated in Applanix POS-AV. Where possible, additional GPS ground base-stations are used to increase accuracy of positional data. In some cases the C-NAV Global Positional Services receiver is used. Overview of the current SHOALS survey platform is given in [1].

4 Data Streams Generated in Air

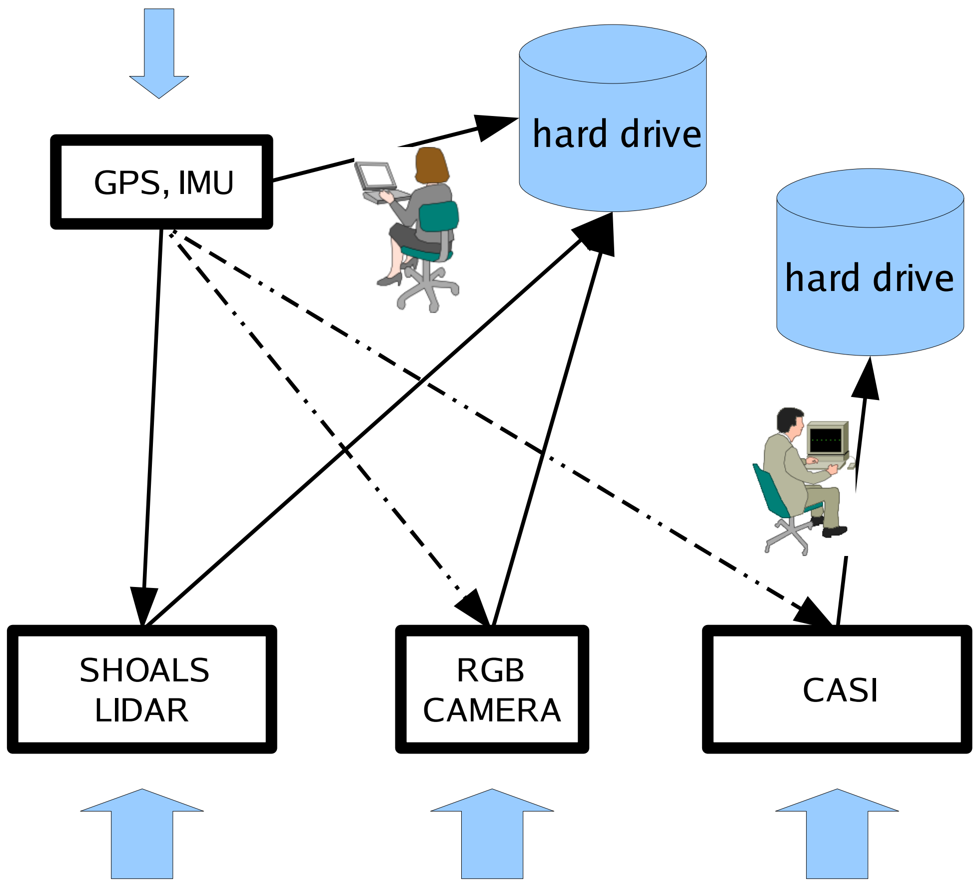


Figure 2: Data Streams Generated in Air

Each sensor subsystem generates digital data that is saved on removable hard drives (see Figure 2). The raw files from bathymetric and topographic LIDAR sensors, files from navigational sensors (GPS and IMU) and images from the color camera are saved on a SHOALS's hard drive. The output of hyperspectral radiometer subsystem is saved on a separate CASI hard drive.

5 Current In-Air Processing

Currently, the functionality of SHOALS hardware is geared toward operating sensors in the air, monitoring the health of subsystems and saving collected raw data to the storage. Limited processing of selected laser pulses is performed for the purpose of the real time survey monitoring. Installed CASI hardware includes an additional CPU, and it has capability to generate radiometrically corrected hyperspectral images.

5.1 Bathymetric and Topographic LIDAR Sensors

No processing. Only a fraction of laser pulses are processed on-the-fly and displayed on the operator screen (waveforms registered by different light receiver channels, estimates of depths or terrain elevation, swath coverage area) for the purpose of real-time monitoring. Upon landing the aircraft the user gets a backup copy of raw data from one of the mirrored hard drives.

5.2 Hyperspectral Radiometer

Limited processing. The CASI instrument is equipped with the ITRES' Real-Time Processing System (RTPS) which does a limited processing (see [7]). The hardware part of RTPS includes an additional CPU and a separate copy of Operating System (MS Windows). The software processes the raw CASI image files as they are created and generates on-the-fly radiometrically corrected images. RTPS creates also a backup copy of raw data. A single band image can be viewed on-the-fly by the operator. Upon landing the aircraft the user gets a backup copy of raw image data as well as radiometrically corrected images. However, the specific format of radiometrically corrected CASI images generated by RTPS make it necessary to apply latter the additional conversion step. It is reported by users that this conversion step takes the same time as directly applying radiometric correction to the raw CASI images.

5.3 Color Camera

Compressing to limit the size of the captured frames. Images are compressed on-the-fly using JPEG format.

6 Software Categories

Most of software used at JALBTCX can be classified into a few categories:

- Waveform Processing Production Category: Software to extract waveforms, depths and elevations from raw LIDAR data.
- LIDAR Edit Production Category: Software to clean, edit and validate bathymetric depths and topographical elevations
- Grids And GIS Production Category: Software to generate grids, vector shoreline,

bare earth DEM and other surface morphology products from clean datasets of bathymetric depths and topographical elevations

- Hyperspectral Mosaic Production Category: Software to generate hyperspectral image mosaics
- RGB Mosaic Production Category: Software to generate color image mosaics
- Fusion Product Production Category: Software to extract optical properties of the water column and the bottom by fusion data from the bathymetric LIDAR and hyperspectral radiometer and subsequently to characterize environment
- Survey Management Category: Software to manage mission planning for the SHOALS system
- Metadata Management Category: Software to manage metadata files for final products

6.1 Software to Extract Waveforms, Depths and Elevations From Raw LIDAR Data

The vendor of the SHOALS system is Optech Inc. and it provides SHOALS Ground Control System (GCS) software package. The software module Davis from GCS includes specialized functions to incorporate raw data into the survey project - the Download function - and to extract waveforms, depths and elevations (Gary C. Guenther's waveform processing, [2], [3]) – the Automatic Processing function. Optech's Downloading and Automatic Processing functions from the DAVIS module are highly autonomous and do not require interactive attention from the user. Changing processing parameters by users is possible.

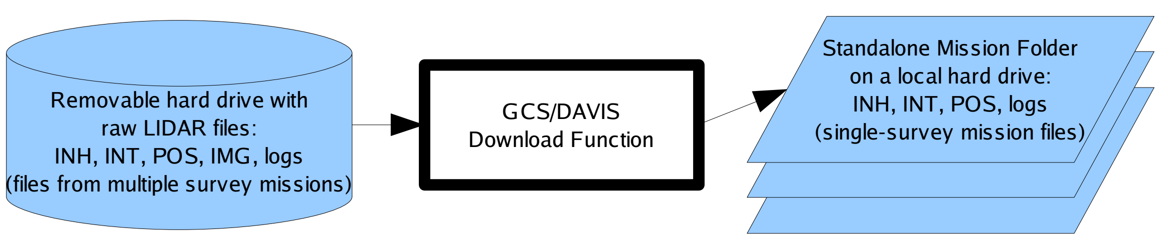


Figure 3 Download Function

The Download function moves the raw LIDAR data (INH, INT, IMG, POS, mission flight plan, and log file) from a removable hard drive to a desktop. The Automatic Processing processes waveform data from the INH files (the input hydrographic file) and INT (the input topographic file) to generate depths and altitudes values. The result of Automatic Processing is given in the form of HOF (hydrographic) and TOF (topographic output) files. Optech Inc. is a sole provider of software for the depths and altitude extraction from SHOALS sensors.

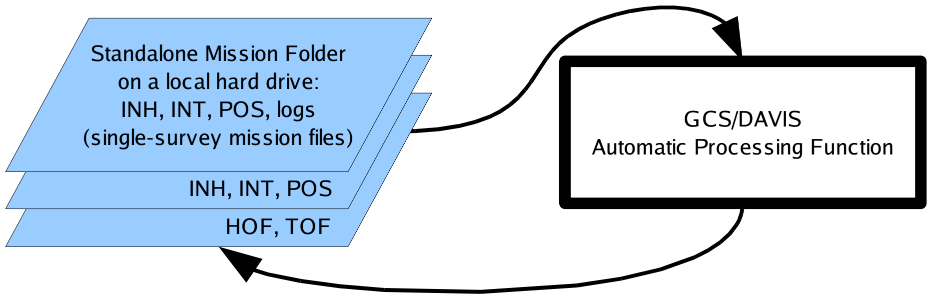


Figure 4 Automatic Processing in Standalone Mode

The Automatic Processing step requires also that the position orientation data is made available. The raw data from INS and GPS are processed using software recommended by manufactures of the INS and GPS units. The preparation of GPS data includes appropriate processing of data from the additional ground GPS stations or the C-NAV receiver.

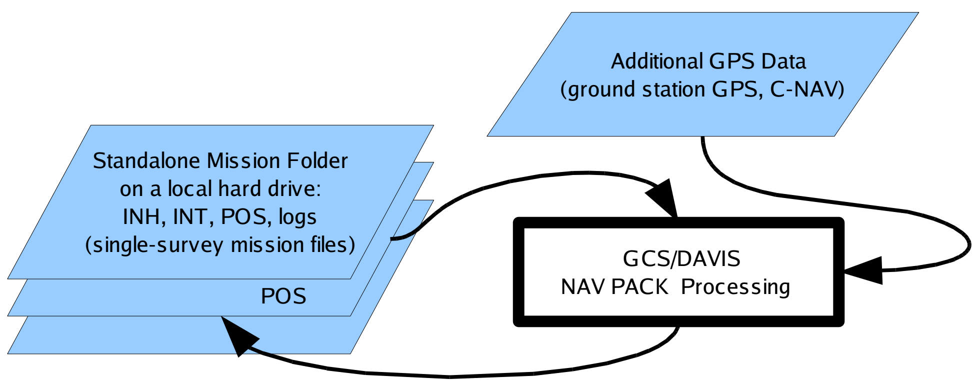


Figure 5 Processing Navigational and GPS Data

Extraction of Waveforms, Depths and Elevations from Raw LIDAR Data	
Software	DAVIS module from SHOALS GCS
Vendor	Optech Inc.
Operating System	MS Windows 32-bit
Software	NAV PACK - Various commercial software for IMU and GPS or C-NAV data
Vendor	Recommended by the IMU and GPS manufacturers
Operating System	MS Windows 32-bit

6.2 Software to Clean, Edit and Validate Bathymetric Depths and Topographical Elevations

The module DAVIS of Optech's GCS integrates Fledermaus 3D from IVS3D Inc. Fledermaus 3D is a software that allows a user to interactively clean, edit, validate and 3D-visualize survey data in a 3D-environment. The Area Based Editor (ABE) is a cleaning, editing and validating software developed
in-house by NAVOCEANO. ABE software was originally developed to clean the multi-beam acoustic sonar data. Both editing software provide users with highly interactive set of GUI windows with the purpose of using visualization techniques to validate large sets of point data (depths or elevations) given in HOF and TOF files. A data point record in HOF or TOF files can have references to additional information, for example a down looking color image.

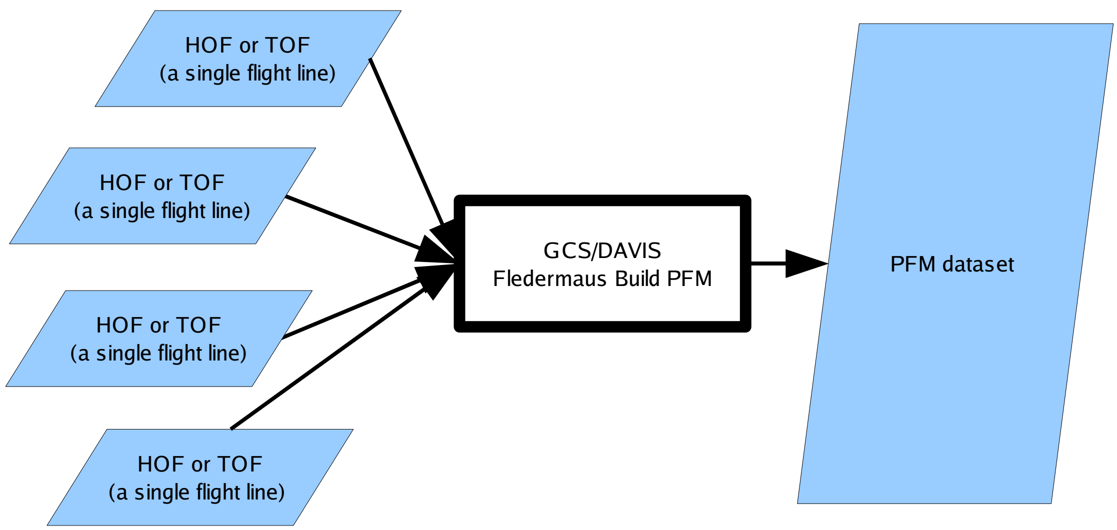


Figure 6: Building PFM Dataset

The primary preparation step is organization of point data records (from a collection of flight lines) into of a 2-dimensional binned structure called a Pure File Magic (PFM) dataset (Figure 6). Even thought generating of PFM dataset is completely automatic, it is a time consuming operation because of intensive I/O hard drive activities. The size of a PFM dataset can often reach a few gigabytes.

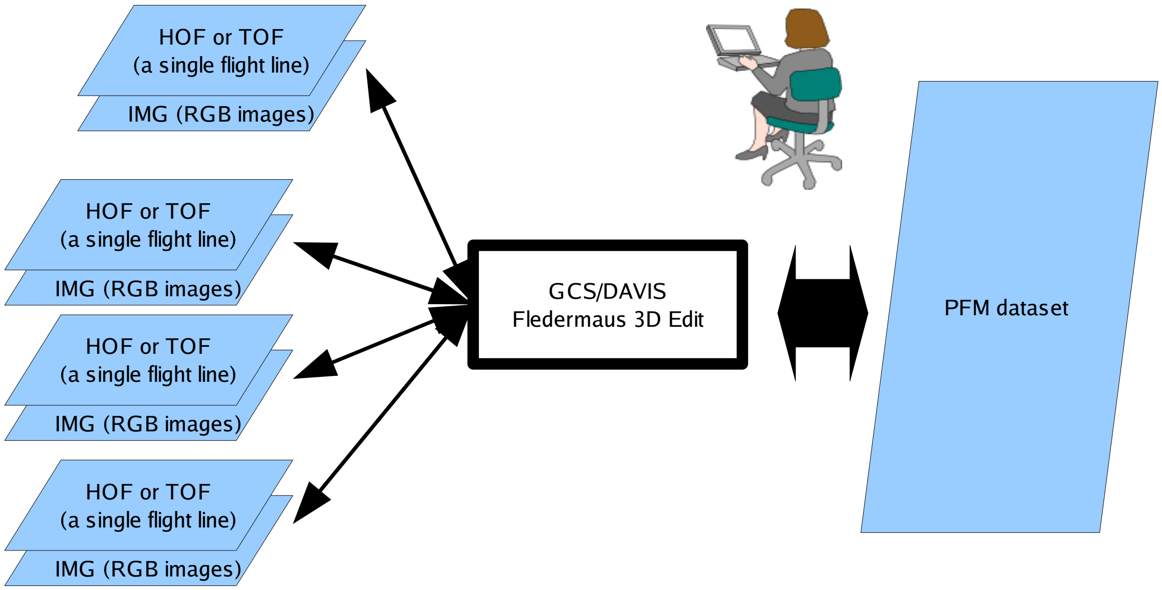


Figure 7: Cleaning, Editing and Validating with Fledermaus

After generating a PFM dataset, users interactively validate depths or elevations (Figure 7). The validation step is very time consuming. As the outcome of data validation process, the validation flags are set for point data records in the PFM dataset as well as in the corresponding data sources (HOF and TOF files).

Cleaning, Editing and Validating Bathymetric Depths and Topographical Elevations	
Software	Module DAVIS of GCS with Fledermaus 3D
Vendor	Optech Inc.
Operating System	MS Windows 32-bit
Software	Fledermaus 3D
Vendor	IVS3D, Inc.
Operating System	MS Windows 32-bit
Software	Area Base Editor from the PFM_ABE software package
Vendor	NAVOCEANO
Operating System	Linux

6.3 Standalone Mode and Project Mode of Operations in Ground Control Software

Optech designed the Ground Control Software (GCS) software to be a comprehensive tool for processing SHOALS LIDAR data. GCS consists of three modules – MAPS, DAVIS and STARS. The MAPS module is used for a project setup, mission (flying survey) planning, and survey management. The DAVIS module is used for data

downloading, automatic data processing (waveform processing) and data cleaning, editing and validating with IVS3D Fledermaus. The STARS module is used for statistical tracking and reporting. GCS software is available on MS Windows only.
Cleaning, edition and validation of LIDAR data is organized in DAVIS into two modes of operations – the Standalone mode (Figure 8) and the Project mode (Figure 9). In Standalone Mode the LIDAR data does not have to be yet committed to a specific project, but the processing can be done only for results of single survey mission. In Project Mode the multiple LIDAR data can be included and worked upon as a single project.

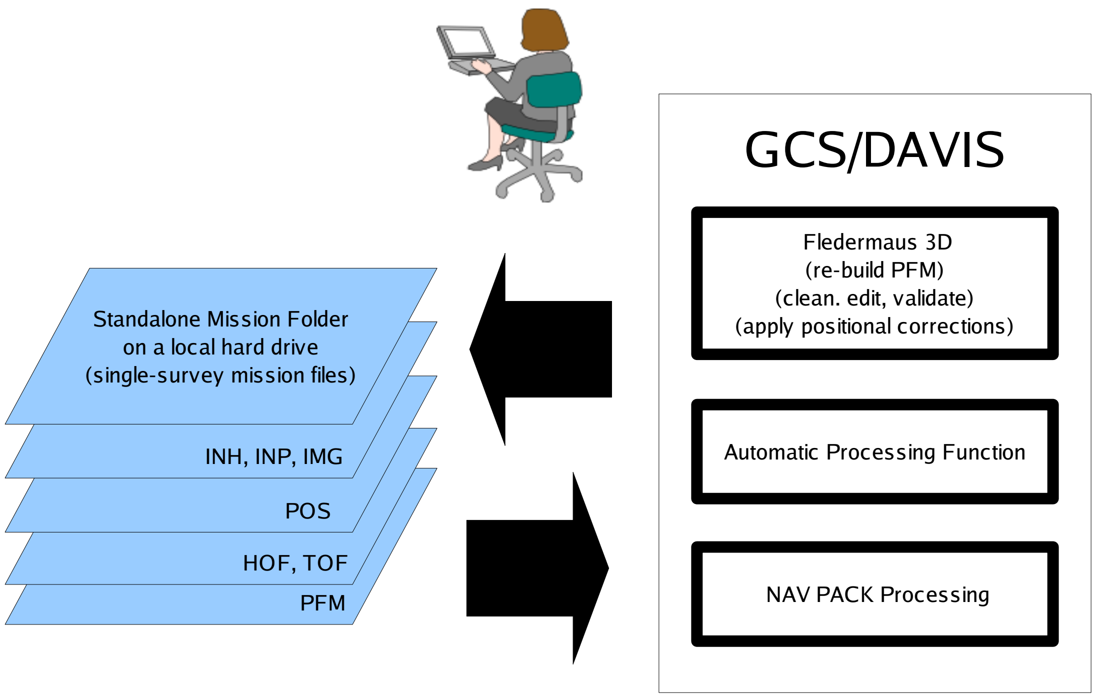


Figure 8: Cleaning, Editing and Validating in Standalone Mode

The Standalone Mode of operation in GCS/DAVIS is used to do an initial cleaning of LIDAR data, usually in the field office. Standalone Mode is applicable only to raw LIDAR datasets collected for a single survey mission (one flight plan). This mode uses Download Function from GCS/DAVIS to move raw datasets (INH, INT, IMG, POS, mission flight plan, and log file) to the desktop (a local drive as a rule). User is expected to run the Automatic Processing function (waveform processing) from GCS/DAVIS. The results of Automatic Processing will be HOF or TOF files for each flight line. Then, the geographical coverage extend can be checked visually in the GUI window, a depth-colored map is visible, and the individual waveforms for each pulse can be examined. In

Standalone Mode, the user is also expected to generate a PFM and perform basic cleaning procedures with Fledermaus 3D (and ABE ,if necessary). The results of the initial validation are automatically saved into HOF and TOF files.

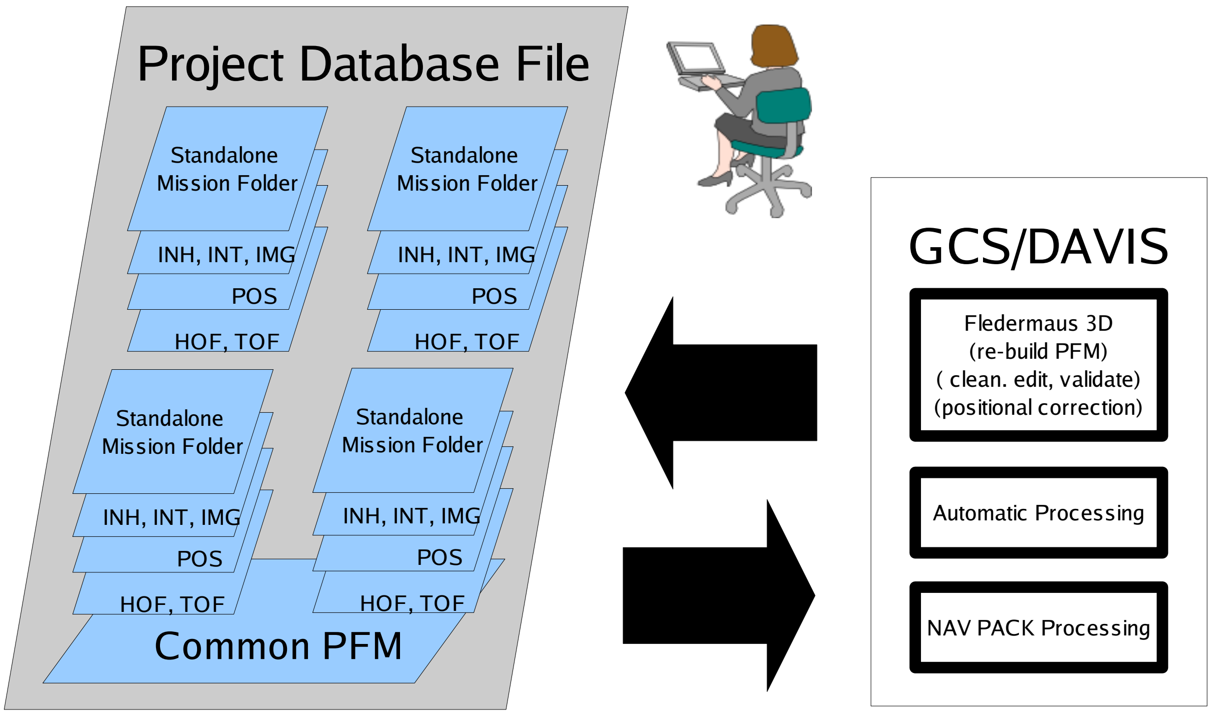


Figure 9: Cleaning, Editing and Validating in Project Mode

The Project Mode of operation in GCS/DAVIS is used to work on LIDAR datasets from multiple missions. These datasets have to be already processed in the Standalone Mode. The user has the ability to selectively choose (commit) which flight-line to include in the project, based on the previous work in the standalone mode. Both the raw LIDAR files and derived HOF and TOF files are committed. A single PFM is built. After committing all required flight lines, the user will do in-depth data validation and cleaning in Fledermaus (and ABE, if necessary). If needed, the user will cycle many times between steps of selectively applying positional corrections, re-running Automatic Processing , rebuilding the PFM, and editing in Fledermaus (or ABE). The results of cleaning and validation are saved into HOF and TOF files

6.4 Software to Generate Grids, Vector Shoreline, Bare Earth DEM and Other Surface Morphology Products From Clean Datasets of Bathymetric Depths and Topographical Elevations

Generating Grids, Vector Shoreline, Bare-earth DEM from Clean LIDAR Datasets	
Software	Lidar Analyst extension for ArcGIS
Vendor	Leica Geosystems Geospatial Imaging, LLC
Operating System	MS Windows 32-bit
Software	ArcMap and ArcView applications from ArcGIS Desktop
Vendor	ESRI
Operating System	MS Windows 32-bit
Software	QT Modeler
Vendor	Applied Imagery
Operating System	MS Windows 32-bit
Software	MatLab
Vendor	The MathWorks, Inc.
Operating System	MS Windows 32-bit (supported also on Linux, Linux x86_64, Mac OS X, MS Window 32-bit 64-bit)
Software	5km Area Block Selection Program
Vendor	NAVOCEANO
Operating System	Linux
Software	Various units conversion software
Vendor	USACE
Operating System	MS Window 32-bit

Cleaned LIDAR datasets are used by USACE to generate various hydrographic and topographic grid products as TIN grids or DEM grids, the bare earth DEM grids or specialized vector information as a zero contour to map the shoreline boundary (Figure 10). From cleaned flight dataset, XYZ coordinates are extracted for points in an area of interest, usually a 5 km length area block along a coast, using the custom 5km Area Block Selection Program. If it is necessary, the geographical positions and dimension units are transformed appropriately using various USACE software.

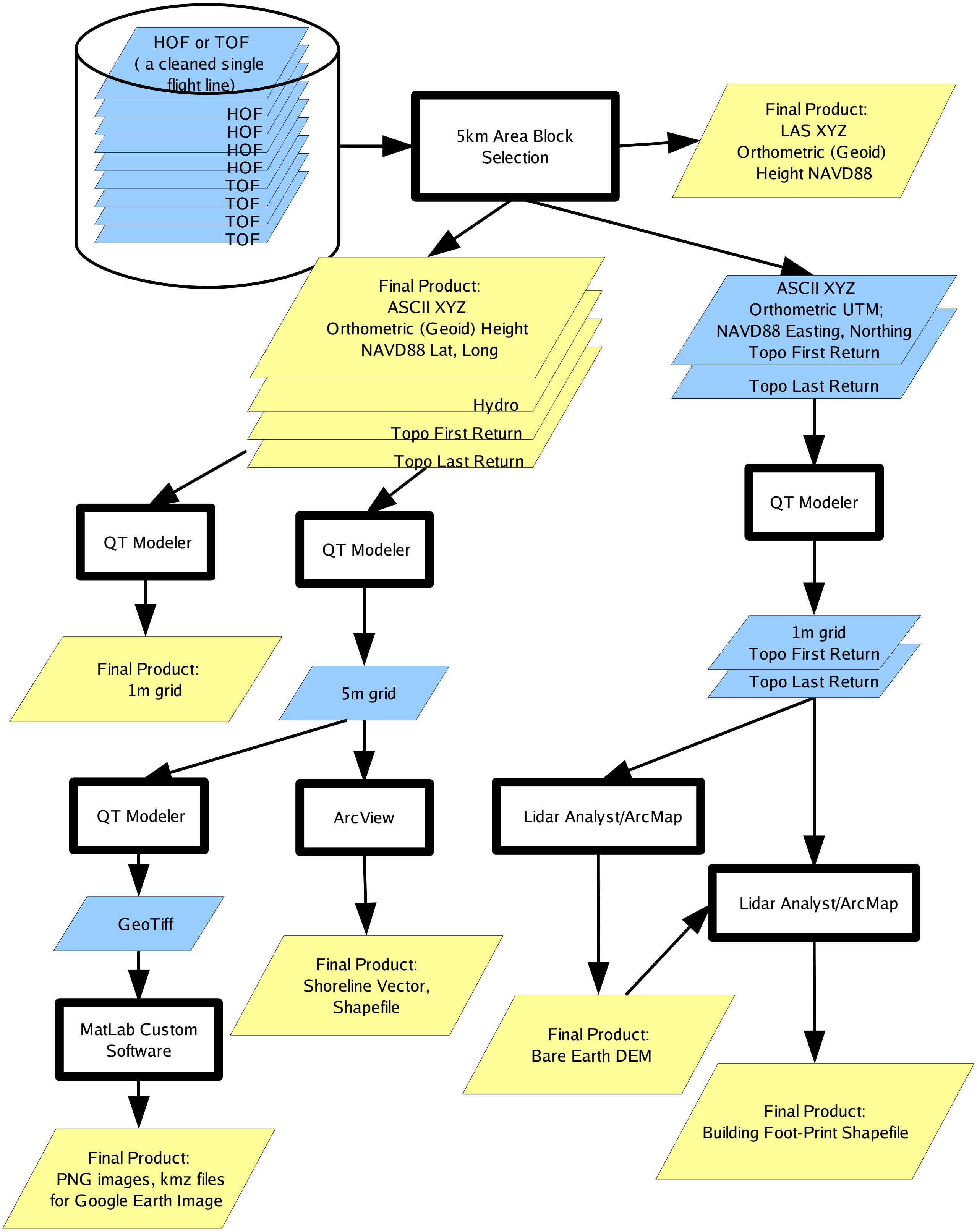


Figure 10: Generating Grids and Vector Products from Clean Datasets

The QT Modeler software is used to generate various grids and GeoTIFF images. Topographic and GIS data processing applications as ArcMap, ArcView and Lidar Analyst are used to generate specialized raster and vector products. These topographic and GIS applications have extensive GUI features and require specialized training for skilled usage by users.

In addition, from low resolution grids, the survey coverage images are generated and put on the publicly accessible JALBTCX server. The Google Earth Image application from Google Inc. can be used to visualize the SHOALS survey coverage of U.S coastline, superimposed on satellite images provided by Google. The necessary image position information for the Google Earth Image application is generated by a custom MatLab program.

6.5 Software to Generate Hyperspectral Image Mosaics

Generating Hyperspectral Image Mosaics	
Software	ITRES Standard Processing Software
Vendor	ITRES Research, Ltd
Operating System	MS Windows 32-bit (supported on Linux)
Software	FORTRAN program TAFKAA with a custom GUI
Vendor	Naval Research Laboratory, Washington, DC
Operating System	MS Windows 32-bit (supported on)
Software	DMagic from Fledermaus
Vendor	IVS3D
Operating System	MS Windows 32-bit
Software	ENVI
Vendor	ITT Visual Information Solutions
Operating System	MS Windows 32-bit (supported also on MS Windows 64-bit, Mac OS X, UNIXes 32-bit and 64-bit)

For each flight line CASI sensor generates a raw CASI image file. ITRES, the manufacturer of the CASI sensor provides users with the Standard Processing Software package. The ITRES Standard Processing Software package consists of mostly command line executables, run by a user as part of a DOS batch script. ITRES programs are run separately for each CASI image.

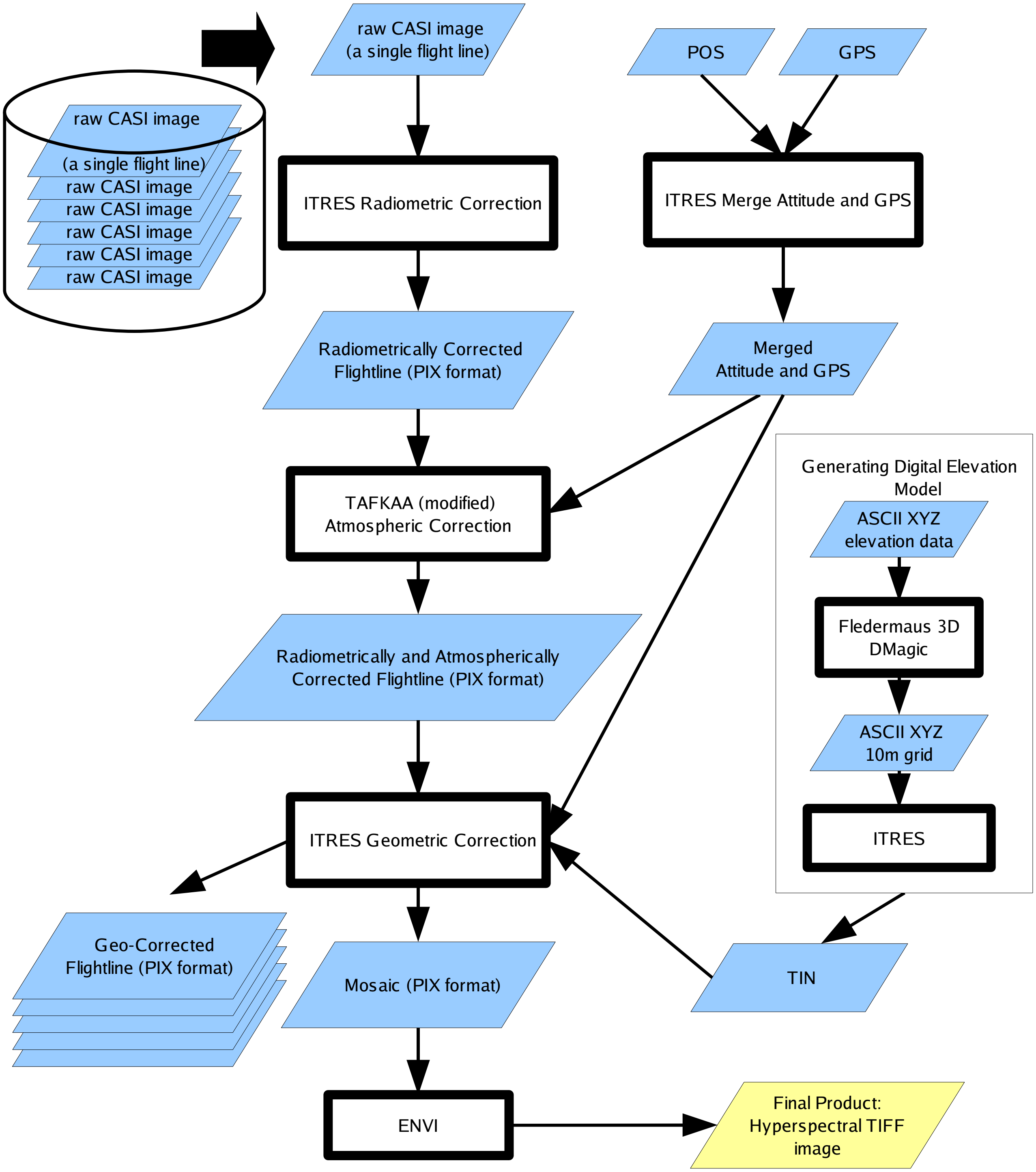


Figure 11: Processing Flow for Hyperspectral Image Mosaic

The process of generating a hyperspectral image mosaic from raw CASI images consists of the following main steps (Figure 11):

- using ITRES program radcorr to apply radiometric corrections to each raw CASI image

- using ITRES programs to prepare and merge attitude and GPS data for each flight line
- using NRL's FORTRAN program tafkaa to apply atmospheric corrections to radiometrically corrected CASI images
- generate a TIN using Fledermaus DMagic and ITRES software
- using ITRES program geocorrect to generate a georectified CASI image for a given flight line and insert it into a common mosaic image
- using ENVI to generate custom-sized hyperspectral TIFF images

6.6 Software to Generate Color Image Mosaics

The following are steps performed to produce a mosaic from images taken by the down-looking RGB camera:

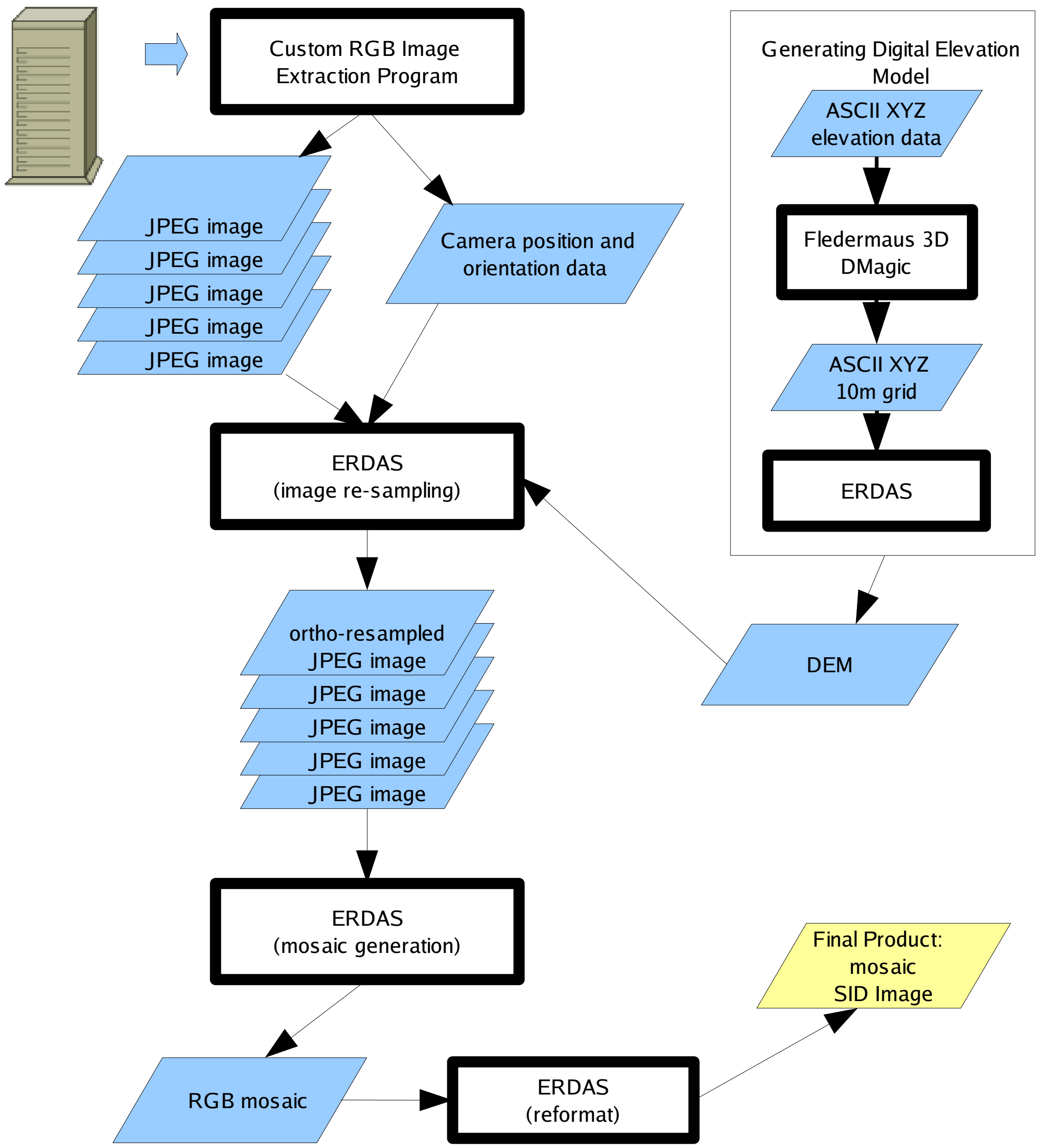
- extract JPEG images for the requested area and generate a file with position and orientation of RGB camera for each recorded image; a custom program is used
- generate a Digital Elevation Model file using Fledermaus DMagic and ERDAS
- use ERDAS software to ortho-resample each JPEG image separately
- use ERDAS to generate mosaic for image collection
- use ERDAS to convert mosaic images to an appropriate compressed format

Generating Color Image Mosaics	
Software	ERDAS Imagine
Vendor	Leica Geosystems Geospatial Imaging, LLC
Operating System	MS Windows 32-bit
Operating System	MS Windows 32-bit
Software	Fledermaus and Dmagic
Vendor	IVS3D, Inc.
Operating System	MS Windows 32-bit
Software	Custom program to determine the orientation and position of the RGB camera
Vendor	NAVOCEANO
Operating System	Linux

Results of processing include the following output images:

- depth image
- ground and seafloor reflectance at 532nm
- attenuation at 532nm

- hyperspectral passive surface reflectance
- hyperspectral passive diffuse attenuation
- hyperspectral passive water volume reflectance
- hyperspectral passive seafloor reflectance



Drawing 12: Processing Flow for RGB Mosaic Generation

6.7 Software for Rapid Environmental Assessment by Extracting Optical Properties of the Water Column and of the Seafloor Reflectance by Data Fusion of the Bathymetric LIDAR and Hyperspectral Radiometer Sensors

The Optech's software Rapid Environmental Assessment (REA) is an IDL language extension to the software package ENVI. This application processes both bathymetric LIDAR data and CASI hyperspectral data to generate estimate of bottom reflectance in all spectral bands present in CASI data using recorded waveforms for the green (532nm) laser to remove optical effects of the water column. The required LIDAR data at 532nm are obtained in the form of BRF files that are generated at the initial LIDAR waveform processing stage (with the updated Optech GCS/DAVIS Automatic Processing function). The CASI raw data are preprocessed by applying radiometric correction with ITRES Standard Processing Software and atmospheric corrections with NRL TAFKAA software.

Rapid Environment Assessment by Data Fusion	
Software	Rapid Environment Assessment Software extension to ENVI
Vendor	Optech International
Operating System	MS Windows 32-bit
Software	ENVI
Vendor	ITT Visual Information Solutions
Operating System	MS Windows 32-bit (supported on MS Windows 64-bit, Mac OS X, various UNIXes 32-bit and 64-bit)
Software	ITRES Standard Processing Software
Vendor	ITRES Research, Ltd
Operating System	MS Windows 32-bit
Software	FORTRAN program TAFKAA
Vendor	Naval Research Laboratory, Washington, DC
Operating System	MS Windows 32-bit

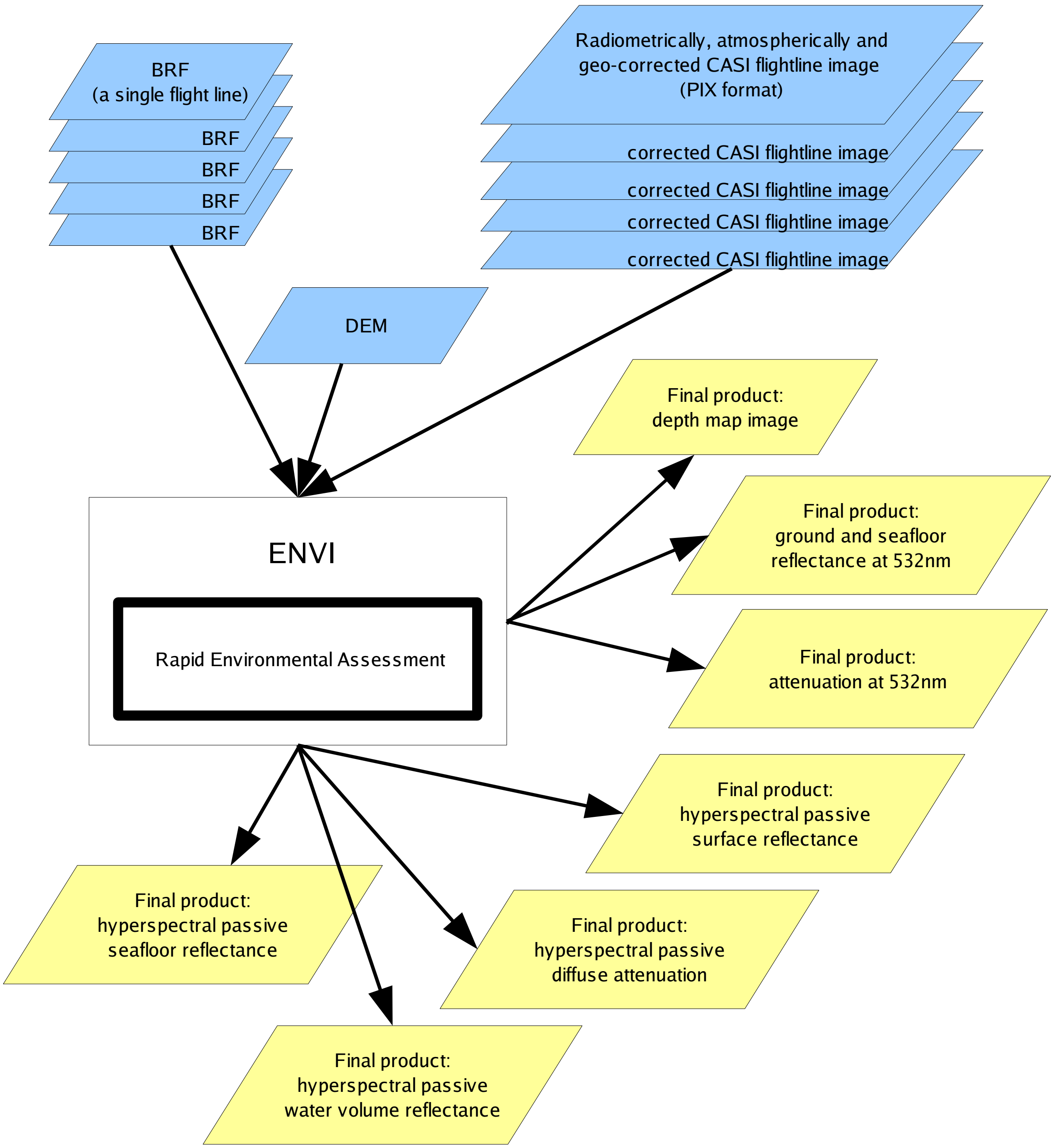


Figure 13: Processing Flow for Rapid Environmental Assessment

6.8 Software to Manage Mission Planning for the SHOALS System

The vendor of the SHOALS system is Optech Inc. and it provides SHOALS Ground Control System (GCS) software package. The software module MAPS from GCS has GUI functions to do mission planning and survey management. The created mission file is then uploaded to SHOALS airborne computer. The SHOALS mission planning and survey management are highly interactive operations. Optech Inc. is a sole provider of software for this step of processing.

Mission Planning	
Software	MAPS module from SHOALS GCS
Vendor	Optech Inc.
Operating System	MS Windows 32-bit

6.9 Software to Manage Metadata Files for Final Products

USACE and US Navy follow federal standards in augmenting final digital products with metadata. The current SHOALS system has no capability to generate metadata associated with each raw output from its sensors. CorpsMet95 software generates metadata in TEXT format. ArcGIS Desktop applications generate metadata in the preferred XML format, and are more user-friendly than CorpsMet95.

Managing Metadata Files for Final Products	
Software	ArcView application from ArcGIS Desktop
Vendor	ESRI
Operating System	MS Windows 32-bit
Software	CorpsMet95
Vendor	USACE
Operating System	MS Windows 32-bit

7 Overview of Processing Hardware

The processing hardware used in the JABLTCX office, Kiln, MS, consists of approximately 20 desktop computers and a few networked RAID arrays. Majority of desktop computers have a single Intel Pentium 4 processor, with 32-bit MS Windows XP, from 1GB to 2GB of RAM, with graphical cards capable of driving dual monitors. As a rule each desktop has two digital LCD monitors. These desktops are equipped with large hard drives. All desktop computers serve as the processing workstations for all phases of SHOALS' data processing, Four computers are dual Intel Xeon processors with 4 GB of RAM, devoted to run GIS-type applications and to produce color mosaic images. Two newer computers have 64-bit Intel EM64T processors, with 8 GB of RAM, running the 64-bit MS Windows.

The networked RAID arrays are rack mounted Linux file servers. Except one, they are various StorageWare models from Pogo Linux, Inc.. Most Linux file servers have two Intel Xeon CPUs with 4 GB of RAM and 3.2 TB of storage in the RAID arrays. The newest Linux storage server has two Intel Xeon EM64T processors, 16 GB of RAM and 16 TB in RAID storage. Linux servers act as NFS-type mass storage for desktop computers. NAVOCEANO's custom software, including the PFM_ABE software package is installed on all Linux servers.

All computers in the JABLTECX office are connected to 10/100/1000 Ethernet switches. In the past all desktop computers had at least 100MB/s Ethernet network cards, but now majority of computers have being equipped with Giga-Ethernet network cards.

8 Scope of Processing in Survey Field Office

A survey field office is usually a hotel room. It is equipped with a few desktop computers networked with one standalone RAID storage unit. All equipment is shipped there from the main JABLTCX office. Field office computers are equipped with the same software as ones in the main office. After a day of surveying, removable hard drive are brought to the field office for archiving and initial processing. Usually, only hydrographic and topographic LIDAR raw data are undergoing immediate processing. The main purpose of performing processing of LIDAR data in the field office is to provide a fast feedback to the survey management about the coverage progress and quality of collected data. GPS and IMU data are appropriately processed, including GPS data from any ground station. Raw files from SHOALS' LIDAR sensor are processed to extract waveforms, depths or elevations. These automatic steps are followed by a labor intensive data cleaning with

Fledermaus 3D or ABE software. The same software (see Sections 6.1, 6.2) as in the main office is used to perform this processing. No farther processing than LIDAR data cleaning and validation is done in the field. However, if a need arises, more involved processing can be performed in the field to generate bathymetric or topographic grids and to derive GIS type products.

9 Microsoft Windows 64-bit And 32-bit Applications

Microsoft Windows XP Professional x64 Edition is capable of running both 64-bit and 32 bit applications side by side. Microsoft claims that 32-bit application can use full 4 GB of memory address space, which is a significant gain over usual 2 GB part of 4 GB address space under the 32-bit MS Windows. A larger address space is claimed to improve performance of memory constrained 32-bit applications. A sixty-four-bit native application is permitted to use much larger memory resources, currently 8 TB of virtual memory. The current version of the Windows XP Professional 64-bit for 1 to 2 CPUs can handle 128 GB physical memory, which is a radical increase from 4 GB for the 32-bit version.

Conclusion: The 32-bit and 64-bit versions of Windows applications can be run side-by-side under the 64-bit Microsoft Windows XP Professional operating system. The current introduction of 64-bit Microsoft Windows operating system should have a positive effect on the performance of Windows applications as ArcGIS, QT Modeler, Lidar Analyst and similar GIS programs used at JABLTCX, even if 32-bit versions were still used. Future 64-bit versions of GIS software are predicted to perform much better, thanks primarily to larger memory limits.

10 Linux 64-bit and 32-bit Applications

At JABLTCX a Linux operating system, Fedora Core 4, is used only on file servers. A number of NAVOCEANO applications from the PFM_ABE are run directly on 32-bit file servers to take advantage of faster access to files on the RAID storage arrays. Currently, The newest file server has two Intel EM64T processors and runs 64-bit version (x86_64) of Fedora Core. The 64-bit version of Fedora Core is capable of running natively 32-bit applications side with the 64-bit applications on computing hardware with Intel's EM64T or AMD's AMD64 processors. The 32-bit Linux environment usually gives an application 3 GB of addressable memory, out of 4 GB possible address space. A 64-bit Linux application has 256 TB address space. It is claimed that AMD Opteron processor supports currently up to 1TB of physical memory.

Conclusion: The 32-bit and 64-bit versions of Linux applications can be run on the 64-bit Linux servers. Future 64-bit versions of software are predicted to perform much better, thanks primarily to larger memory limits.

11 Creating Software Capable of Using Large Memory

Gigabyte-size files are routinely generated as the result of operating SHAOALS sensors and later, in the subsequent data post-processing activities. Large PFM datasets, each having a few gigabytes in total, are generated and operated onto, when LIDAR data are cleaned, edited and validated with Fledermaus or ABE software. Software as QT Modeler, ArcGIS and other GIS applications routinely deal with grids containing millions of points. Large files are created in the production of hyperspectral image mosaics. Generating RGB image mosaics requires processing thousands of JPG images. The intensive I/O hard drive activities could be mitigated and overall processing of large files accelerated if more data could be held in the computer main memory. The speed of generating images in GUI windows could be increased if all necessary data were held in memory.

In the 32-bit environments, it is very complicated for programmers to design software capable of using more than 2 GB of RAM. In the 64-bit environments, both in Microsoft Windows and in Linux, only the physical size of the installed memory becomes the limiting factor (see Sections 10 and 11).

Currently, 64-bit computers with 8 GB of memory become cost effective as desktop systems. Prices of the low-end computer servers equipped with 64 GB RAM fell below $20k. The Commercial Of The Shelf (COTS) low priced computers with 4 GB to 16 GB of RAM became the market reality.

Observation: Only one software at JABLTCX, called QT Modeler, is capable of using large memory, up to 2 GB of RAM.

Recommendation: Vendors of software used at JALBTCX should be encouraged to take the advantage of available large RAM and to re-design their software accordingly. Specifically, JABLTCX should initiate dialog with developers of:

- Fledermaus and ABE , to improve handling of PFM datasets and GUI responsiveness. A large memory in a processing computer makes possible to eliminate the intensive I/O to and from a PFM on a hard drive by explicitly utilizing memory in the code or even by creating a primary working copy of the PFM in RAM.
- ITRES Standard Processing Software, to improve geo-rectification and mosaic (PIX) files handling. A large memory in a processing computer makes possible to allocate large arrays in RAM to build larger chunks of the rectified images and mosaic in the memory before committing them to the hard drive.
- ERDAS, to improve RGB images rectification (resampling) and mosaic (IMG) files handling. A large memory in a processing computer makes possible to allocate large arrays in RAM to build larger chunks of the rectified images and mosaic in the memory before committing them to the hard drive.

12 Creating Software Capable to Utilize a Small Multiprocessor Computer

At JALBTCX, the high-end workstations are used for computationally intensive processing as the GIS-type processing, hyperspectral mosaic production, and RGB mosaic production. These workstation have dual Intel processors. Also, all file servers at JALBTCX main office have dual processors.

Two main manufacturers of CPUs, Intel , Inc. and Advanced Micro Devices (AMD), Inc., are selling dual core versions of their CPUs. Because of intensive market competition between these two companies, the pricing of new dual core processors is comparable with the single core versions. Both Microsoft Windows and Linux are already supporting dual core processors.

Currently, prices of the low-end server, with four processor, each dual core , equipped with 64 GB RAM, 1.6TB storage, fell below $24k. Therefore, it is reasonable to expect that in a few years dual core processors become mainstream standard in single, dual and quad computer systems.

Coding software for multiple processors requires use of software parallelization methods. There exist already developed programming techniques for parallelization of software for dual-processor computers, for midrange SMP- servers, for large commercial multiprocessor supercomputing systems, as well as for much cheaper Linux clusters, The standard parallelization techniques include MPI, OpenMP, and use of thread libraries. Operating systems as Microsoft Windows, Mac OS X and Linux are already supporting threading. Some commercial compilers are supporting OpenMP.

Observation: None of the current software used at JABLTCX, both commercial and custom, is capable to utilize multiple processors (CPUs) for the core data processing, even that the operating systems (Microsoft Windows, Linux) and most Graphical User Interfaces (GUIs) of deployed software are fully threaded and able to use multiple processors (CPUs).

Recommendation: Consult software vendors to discuss feasibility of using software parallelization to accelerate processing of:

- LIDAR waveform processing (the Automatic Processing function from GCS/DAVIS). The GCS software reports that this step takes time comparable to the collection time.
- geocorrection step from ITRES Standard Processing of the hyperspectral CASI data. Tests found that the ratio of the collection time to the geocorrection run time is 1 to 3.5. The applicable parallelization techniques could include data partitioning in the time dimension, or partitioning along the spectral bands.
- RGB images rectification (resampling) and mosaic generation, using ERDAS software. The user reported average speed of rectification (resampling) of 400 images in one hour. The applicable parallelization techniques could include task (rectification) spreading among processors.
- inversion step in the Rapid Environment Assessment software. Multiple independent inversions, possible in hundreds, are preformed on a single spectral image. The applicable parallelization techniques could include task (inversion) spreading among processors.

13 Using Vector Instructions – Streaming SIMD Extensions

Intel and AMD processors are now capable of using the vector instruction set called Streaming SIMD Extensions 3 (SSE3). SSE3 vector instructions are calculations performed on sixteen special purpose 128-bit registers. Because of registers size, a single 128-bit register is capable of holding sixteen 8-bit image pixels, or a smaller number of float and integer type of numbers. Code vectorization is beneficial for large homogeneous data, as arrays, and loops operating on homogeneous data and in many cases can provide substantial processing speedup. Programmers usually take advantage of the vector instructions by using optimized libraries and compilers.

Recommendation: Consult software vendors to find out their current level of using the vector instructions in their products for image processing and possibly discuss feasibility of using the SSE3 vector instruction set to accelerate processing of:

- hyperspectral CASI data, with ITRES software or ENVI
- RGB image mosaic with ERDAS

14 Using Large Local Disks to Mitigate I/O Bottlenecks Over Network

The LIDAR cleaning, editing and validating software as Fledermaus 3D bundled with Optech's GCS suffers from the slow I/O when executed in the current network configuration. A user desktop is networked with a RAID storage server. The operating system on the server (Linux) makes the storage available to a MS Window on the desktop as a network drive. Applications GCS and Fledermaus 3D are executed (locally) on the processing desktop but the input files containing LIDAR flight line data, GPS and POS data are located on the server. Also, as a processing rule, Fledermaus 3D and the desktop's CPU is used to initially build a PFM dataset on the remote drive (on the server), creating a lot of I/O activity over a network. The subsequent cleaning, editing and validating processing, a very human intensive and I/O intensive, is again done with Fledermaus 3D executed (locally) on the desktop computer and accessing remotely the PFM. In addition, some editing steps require Fledermaus to access the LIDAR source files located on the server. The policy of keeping PFM datasets on the server has the advantage of avoiding trouble of tracking multiple copies of PFM for the same project.

One way to mitigate I/O over the network could be to execute the editing software at the same location as the source data and PFM. The OGS and Fledermaus 3D are MS Windows applications but creating a MS Windows server is still prohibitively expensive because of license and up keeping costs.

One solution, already often used, is to build the initial PFM on the server using NAVOCEANO tools from the PFM_ABE software package. A user reported a time ratio as 2.5 hrs (GCS/Fledermaus) against 10 min (PFM_ABE). After building the PFM dataset on the server, the editing is continued using GCS/Fledermaus executed on the desktop.

Here are a few illustrations of problems with doing an intensive I/O over network. A GCS/Fledermaus user reported working with a very large collection of points (420,000) and waiting 7 hrs for the Adjust Water function to finish. Another user performed two tests (1) to create the PFM on the local hard drive and it took 20 min and (2) to create the same PFM in the usual place on remote drive (server) and it took 1.5 hrs. For these tests the LIDAR sources were as usual located on the remote drive (server). The final step of quitting the GCS/Fledermaus application, which finalize validation changes from the PFM by committing them to the sources (HOF and TOF files) is reported as being slow by many users.

The problems with slow I/O over network can be also mitigated by using fastest available network connection to file servers, the full duplex Giga Ethernet connection. A different solution can possible use a client side cache file and “file delegation” features from NFS V4.

Recommendation: Executing an application with I/O drive activities done locally w/t the CPU seems to be the most optimal way of designing processing to eliminate bottlenecks of I/O over network. Review network connections from all processing desktops to servers and use available connections at full duplex Giga Ethernet. Consult software vendor of GCS and Fledermaus 3D to find the ways to mitigate I/O hard drives activities over a network for working with PFM datasets and LIDAR source data files.

15 Improving Data Processing Progress Tracking

Currently, there is no in place an automated system to track the progress of processing data from various surveys. Such future system could keep track of task assignments and list accomplished intermediate tasks. A progress tracking system should be accessible to user from their desktops. The tracking system should allow locating all final products as well as intermediate files generated to complete the intermediate tasks. The tracking system could have the ability to view metadata files associated with project files. A care should be taken to have a system that does not impair user's activities by trying to track all present files on hard drives or prevent multiple users to work and finish tasks, regardless of the initial personnel assignments. Since JALBTCX has a mix environment of MS Windows desktops and Linux servers, the reporting system should be WEB based, using WEB browsers to connect to a central server on a designated Linux servers. Simplicity of the system should be the primary consideration, so no integration with existing e-mail or personal calendar applications is required. The primary objective should be to track processing of digital survey data, not a magnitude of usual institutional assignments.

Recommendation: Improve management of survey data post processing activities and individual processing task assignment. Consult software vendors to find software for task reporting and visualizing. A simple, open source solution is recommended to avoid costs of up keeping.

16 Improving Metadata Generation

Currently, the metadata is created only for the final products. Possibly each major step of processing should have a metadata template to allow painless metadata creation. It would be desirable if future survey sensors have a capability to automatically generate initial metadata information. Because of the mix environment of MS Windows and Linux, a flexible (cross-platform) tool should be employed, perhaps in Java. Interoperability of that tool with ArcGIS and other metadata-capable software is desirable. Since USACE is often using metadata in the TEXT format, the tool must be flexible and able to convert between XML and TEXT formats, even thought, the XML format for metadata is preferred.

Recommendation: Optech and ITRES should be consulted on designing metadata templates for the current sensors. A cross-platform (Microsoft Windows and Linux) metadata tool should be employed to aid metadata management. A future airborne survey system should include requirements to automatically generate metadata for raw data from sensors.

17 Future - COTS Processing Computer Hardware After Four Years

Here is given a conservative assessment of mainstream computer hardware available after four years. Such hardware is already available in an expensive custom configuration. It is intention of this specific hardware description to be used as the recommended hardware configuration for software developers implementing recommendations of this report.

Target Computing Platforms: The COTS desktops will be at least dual-processor computers with at least 16 GB of RAM, and 600 GB hard drives. The COTS computational workstations will have at least four CPUs, 32GB of RAM and a RAID storage of 1.6 TB. A COTS Linux server will have at least 8 CPUs, 64 GB of RAM and 8TB of storage. Computers will be running the 64-bit operating systems as MS Windows and a Linux.

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Appendix A Abbreviations

ABE	Area Based Editor – an application from the Navy's PFM_ABE software package
AMD	Advanced Micro Devices, Inc.
ALB	Airborne LIDAR Bathymetry
CASI	Compact Airborne Spectrographic Imager – a spectrometer manufactured by ITRES Research, Ltd.
CHARTS	Compact Hydrographic Airborne Rapid Total Survey – the name of airborne LIDAR survey system
COTS	Commercial Off The Shelf
CPU	Central Pressing Unit
DAVIS	A software module from the Optech's GCS software suite
DEM	Digital Elevation Model
GCS	Ground Control System – a software package provided by Optech Inc. for the SHOALS systems
GeoTIFF	An image and data format
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HOF	Hydrographic Output File - an Optech's format of the SHOALS flight line file containing hydrographic (bathymetric) data as result of waveform processing of raw bathymetric LIDAR data
IMG	ERDAS proprietary image and data format
IMU	Inertial Measurement Unit - the navigational sensor that measures heading (yaw), roll and pitch
INS	Inertial Navigation System
I/O	Input/Output – input and output activities of a computer software
JABLTCX	Joint Airborne Lidar Bathymetry Technical Center of Expertise

JPEG	An image format
Kd	Optical diffuse attenuation coefficient
LIDAR	Light Detection And Ranging
LASER	Light Amplification by Stimulated Emission of Radiation
MAPS	A software module from the Optech's GCS software suite
MPI	Message Passing Interface
MS Windows	Microsoft Windows XP Professional
NFS	Network File System
NRL	Naval Research Laboratory
NAVD88	North American Vertical Datum 1988
NAVOCEANO	The Naval Oceanographic Office
PFM	Pure File Magic – a data format
PIX	A image and data file format used by ITRES for hyperspectral data
POS	Position and Orientation System – the navigational system usually consisting of GPS and INS/IMU
RAM	Random Access Memory
REA	Rapid Environmental Assessment – an Optech's application
RGB	Red, Green and Blue colors
SHOALS	Scanning Hydrographic Operational Airborne LIDAR Survey – the airborne LIDAR system build by Optech Inc.
SHOALS-1000T	Scanning Hydrographic Operational Airborne LIDAR Survey – Optech's 1000 Hz bathymetric LIDAR sensor with Topographic LIDAR capability
SHOALS-3000T20-E	Scanning Hydrographic Operational Airborne Lidar Survey – Optech's 3000 Hz bathymetric LIDAR sensor with 20kHz Topographic LIDAR and hypErspectral capability; introduced June 2005
SIMD	Single Instruction Multiple Data
SSE3	Streaming SIMD – Single Instruction Multiple Data – Extensions

	3
TIFF	An image and data format
TIN	Triangulated Irregular Network
TOF	Topographic Output File – an Optech's format of the SHOALS flight line file containing processed topographic LIDAR data
USACE	U.S. Army Corps of Engineers
WGS84	World Geodetic System 1984

Appendix B Software List

Software	*Vendor*	*Operating System*	*64-bit Ready*
ArcView, ArcMap from ArcGIS Desktop	ESRI	MS Window 32-bit	
Area Base Editor from the PFM_ABE software package	NAVOCEANO	Linux 32-bit	
Custom program to determine the orientation and position of the RGB camera	NAVOCANO	Linux 32-bit	Yes
Custom 5km Area Block Selection Program	NAVOCEANO	Linux 32-bit	Yes
CorpsMet95	USACE	MS Window 32-bit	
GCS (includes modules DAVIS and MAPS)	Optech Inc.	MS Window 32-bit	
ENVI	ITT Visual Information Solutions	MS Window 32-bit (supported on Mac OS X and varies UNIXes	MS Windows 64-bit, various UNIXes 64-bit
ERDAS Imagine	Leica Geosystems Geospatial Imaging, LLC	MS Window 32-bit	
Fledermaus 3D	IVS3D, Inc.	MS Window 32-bit	
ITRES Standard Processing Software	ITRES Research, Ltd	MS Window 32-bit (supported on Linux 32-bit)	

Software	***Vendor***	***Operating System***	***64-bit Ready***
Lidar Analyst extension for ArcGIS	Leica Geosystems Geospatial Imaging, LLC	MS Window 32-bit	
MatLab	The MathWorks, Inc.	MS Window 32-bit (supported on Linux)	Yes
PFM_ABE	NAVOCEANO	Linux	most
QT Modeler (QT Viewer, QT Reader)	Applied Imagery	MS Window 32-bit	
Rapid Environmental Assessment (REA) extension to ENVI	Optech International	MS Window 32-bit	
TAFKAA	Naval Research Laboratory, Washington, DC	MS Window 32-bit	
Various commercial software for IMU, GPS and C-NAV data	Vendors recommended by manufacturer of IMU, GPS and C-NAV sensors	MS Window 32-bit	
Various unit conversion software	USACE	MS Window 32-bit	